MODELING ASTERIOD IMPACT AND TSUNAMI

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ABSTRACT

A study of the interaction of a typical stony asteroid (density of 3.32 g/cc and velocity of 20 km/sec) with the atmosphere, and a 5 km deep ocean with a basalt bottom has been modeled using the CTH computer code for multidimensional, multi-material, large deformation, strong shock wave physics. Two dimensional axial symmetric calculations were performed for up one minute of real time. This was adequate to follow the ocean cavity formation until maximum cavity size for 250, 500, and 1000 meter diameter asteroids. The maximum hemispherical cavity size was 2500, and 5000 in radius for the 250 and 500 meter asteroid. The maximum cavity size was a 5 km deep, 10 km radius cylinder for the 1 km diameter asteroid.

The collapse of the cavities, the resulting tsunami waves and the propagation for up to 150 km was modeled using the the *ZUNI* code which solves the incompressible Navier-Stokes equations.

A 250 meter asteroid would result in less than a a 10 meter high tsunami after 60 km of travel, a 500 meter asteroid would result in a 100 meter high wave after 30 km of travel and in a 10 meter high tsunami after 200 km of travel. The tsunami generated by a 1 km diameter asteroid would run 80 km before the tsunami wave amplitude was less than 100 meters and 500 km before it was less than 10 meters. The tsunami period, wavelength and velocity increases with run distance while the amplitude decreases. The tsunami wave amplitudes and velocities are less than the shallow water wave values.

ASTEROID TSUNAMIS

The Sandia CTH shock physics code was used in 1994 by Crawford and Boslough to accurately simulate what happened when comet Shoemaker-Levy 9 plunged into Jupiter's atmosphere as described in references 1 and 2. Months later, the world's astromers watched the Sandia predicted event unfold in real life through the Hubble space telescope.

The CTH code was used to model a three-dimensional 120 square mile space of the New York City metropolitan area, the air above, and the water and earth below using 100 million cells. An asteroid 1.4 kilometers in diameter struck the ocean at a 15 degree angle 25 miles south of Brooklyn, New York. The results of the calculations are shown in reference 3. An impact plume containing superheated water, earth and other debris blanketed major portions of Long Island. The calculation required 18 hours on the U. S. Department of Energy's ASCI teraflops computer to run to 8.4 seconds after impact.

Tsunami waves generated by earthquakes have typically had a maximum deep ocean amplitude of 10 meters and periods of 500 to 2000 seconds. Tsunami waves with amplitudes of approximately 100 meters are referred to as mega-tsunamis and may be generated by landslides such as the 105 Ka Lanai event described in reference 4 or by asteroid impact with the ocean described in reference 5. The landslide tsunamis have shorter periods and thus the tsunami wave amplitude is not maintained as the wave travels from the source. Large asteroid generated tsunami waves have long periods and waves with large amplitudes that can propagate across an ocean basin.

MODELING THE ASTEROID TSUNAMI

A study of the interaction of a typical stony asteroid (density of 3.32 g/cc and velocity of 20 km/sec) with a 5 km deep ocean with a basalt bottom has been modeled using the CTH computer code for multidimensional, multi-material, large deformation, strong shock wave physics described in reference 6. Two dimensional axial symmetric calculations were performed using a 5, 50 and 100 meter grids for up to one minute of real time. This was adequate to follow the ocean cavity formation until maximum cavity size for 250, 500, and 1000 meter diameter asteroids. The maximum hemispherical cavity size was 2500, and 5000 in radius for the 250 and 500 meter asteroid. The maximum cavity size was a 5 km deep, 10 km radius cylinder for the 1 km diameter asteroid. The interface profiles at various times are shown in Figure 1 for the 500 meter diameter asteroid. The maximum cavity occurs at 21 seconds. The profile at maximum transient cavity size is shown in Figure 2 for the 250 meter diameter asteroid, and in Figure 3 for the 1000 meter diameter asteroid.

The collapse of the cavities, the resulting tsunami waves and the propagation for up to 150 km was modeled. The modeling was performed using the *ZUNI* incompressible Navier-Stokes code. The *ZUNI* code is described in reference 7. The calculations were performed on 230 Mhz Pentium personal computers.

A summary of the tsunami wave heights at various distances of run in a 5000 meter deep ocean are shown in Table 1. A 250 meter asteroid would result in less than a a 10 meter high tsunami after 60 km of travel, a 500 meter asteroid would result in a 100 meter high wave after 30 km of travel and in a 10 meter high tsunami after 200 km of travel, a 1 km diameter asteroid would run 80 km before the tsunami wave amplitude was less than

100 meters and 500 km before it was less than 10 meters. The tsunami period, wavelength and velocity increases with run distance while the amplitude decreases. The tsunami wave amplitudes and velocities are less than the shallow water wave values shown in Table 2. As described in reference 7, the shallow water cavity collapses from the side while the Navier-Stokes cavity collapses primarily from the bottom. The resulting wave amplitude after collapse at the initial cavity radius for the Navier-Stokes cavity is less than half of that for the shallow water cavity.

DISCUSSION

Some of the estimates in the technical literature of tsunami wave heights generated by asteroids are described by Verschuur in reference 8, Steel in reference 9, and Lewis in reference 10. A one kilometer stony asteroid traveling 20 kilometers/sec has been estimated to generate a 200 meter high tsunami after 1000 kilometers of run. As shown in Table 1, the tsunami wave amplitude would be about 6 meters.

A 500 meter stony asteroid has been estimated to generate a 50 to 100 meter high tsunami after 1000 kilometers of run. The wave amplitude from Table 1 would be less than 2 meters. If one assumes that the tsunami wave travels 1000 kilometers as a shallow water wave, the geometrical aspect alone would lower the wave amplitude to about 5 meters. The tsunami wave period after the wave has run 10 kilometers is about 3 minutes and the wave length is about 30 kilometers. In a 5 kilometer ocean this wave is not a shallow water wave.

Most tsunami waves that have been observed after traveling across the ocean have periods longer than 10 minutes. As shown in reference 11, this is because short wave length tsunamis are so dispersive that as they propagate long distances, their amplitude decreases by an order of magnitude.

The 500 meter diameter stony asteroid generated tsunami has been attributed in the press and technical literature as presenting a hazard throughout the entire Atlantic or Pacific basin regardless of where it impacts the ocean. It would actually require an asteroid with a diameter greater than 2 kilometers.

The modeling of the cavity generated by the asteroid impact and the use of the maximum cavity size to calculate tsunami wave amplitudes furnishes wave amplitudes as a function of distance of run that are uncertain by at least a factor of two. Future modeling of asteroid generated tsunami waves need to be performed using numerical models that will follow the compressible to incompressible fluid dynamics as a single continuous problem. The effect of asteroid velocity, density, composition and the state properties of the ocean floor need to be evaluated.

Acknowledgments

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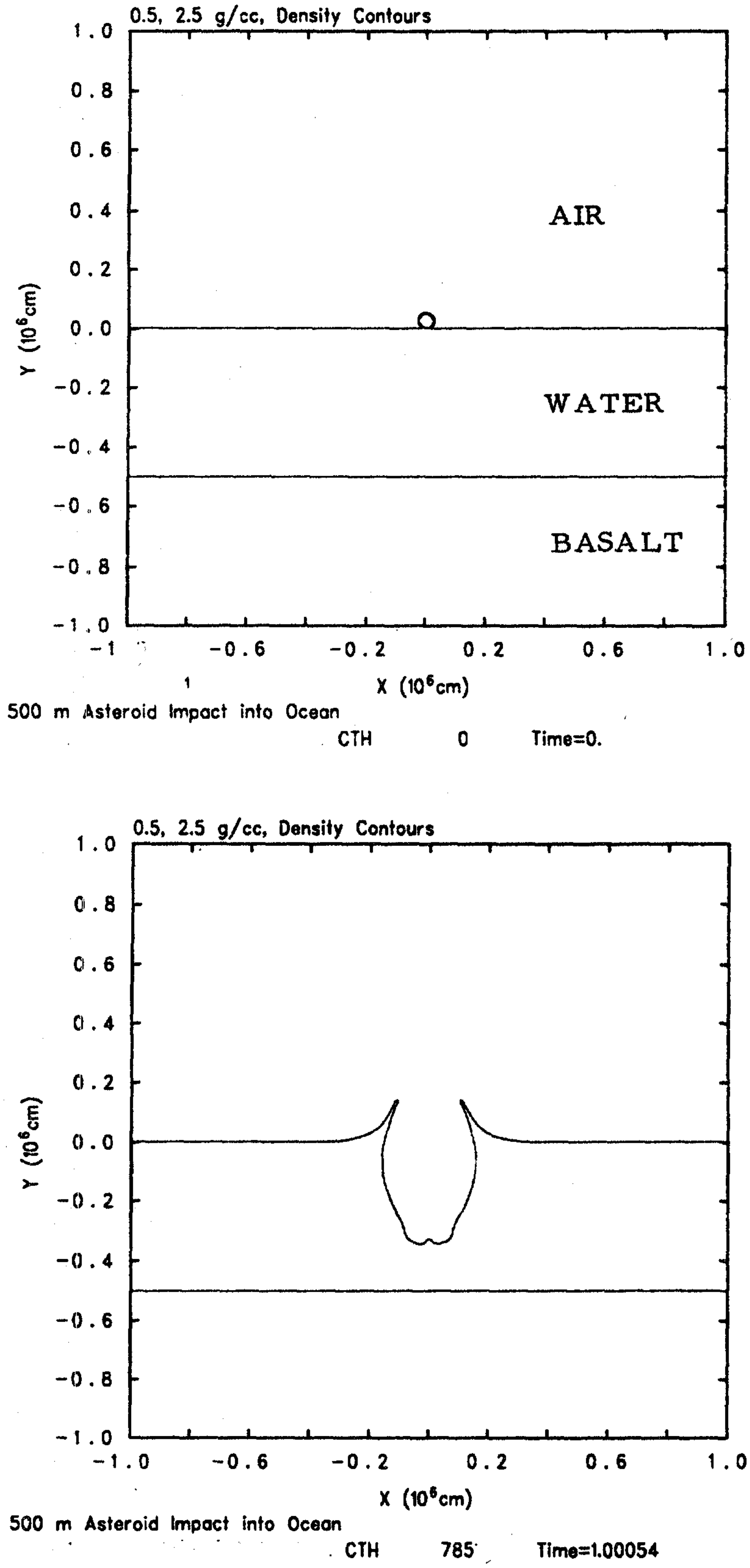
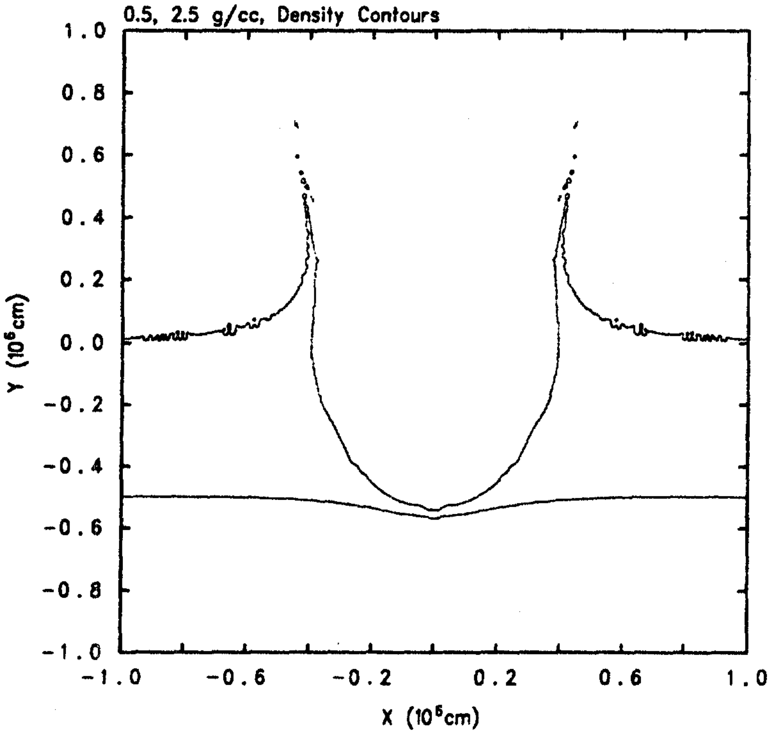
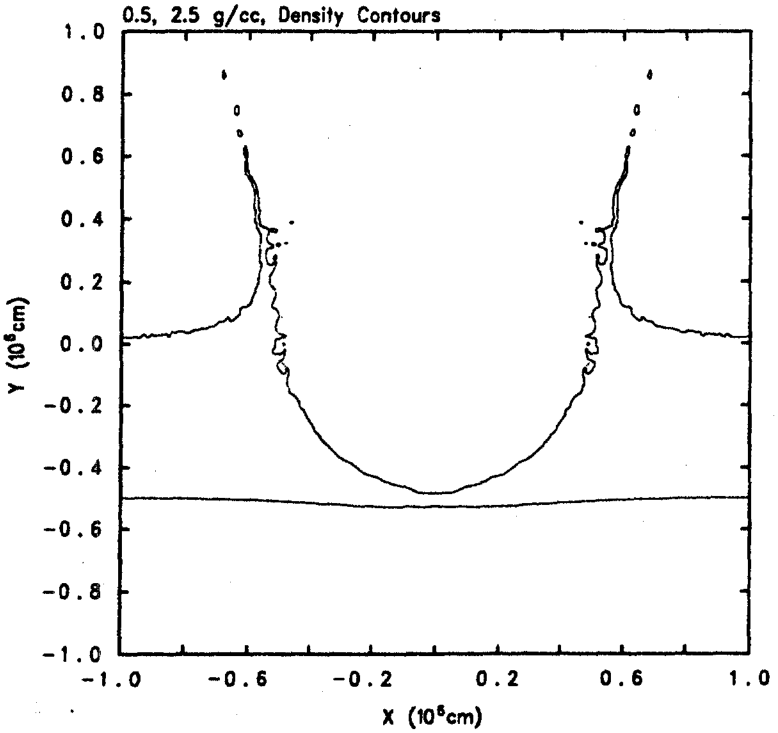


Figure 1. A 500 meter diameter, dunite asteroid moving 20 kilometers/second impacting 5000 meters of water and a basalt ocean floor. The maximum cavity occurs at 21 seconds.



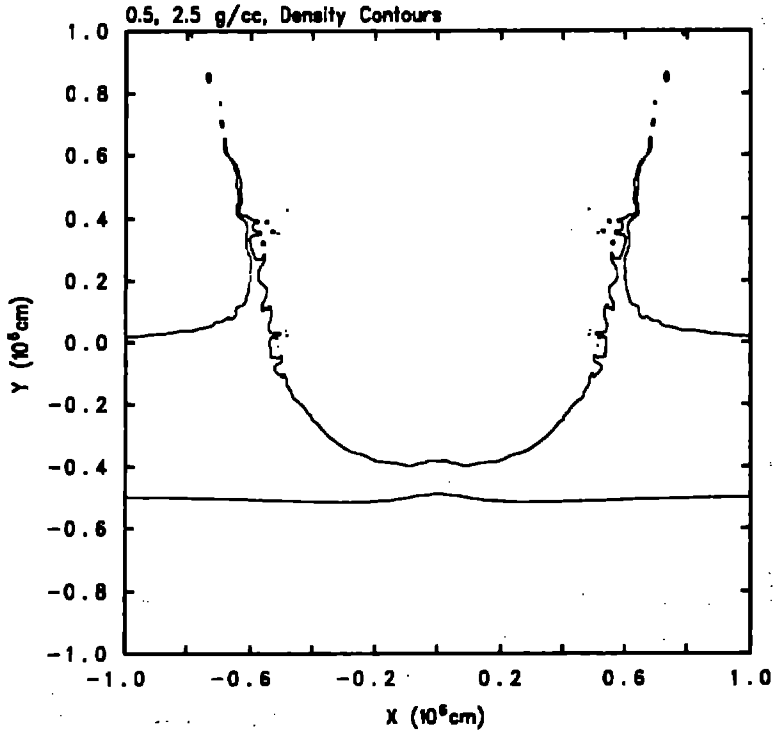
500 m Asteroid Impact into Ocean

CTH 3124 Time=1.00024×10^1

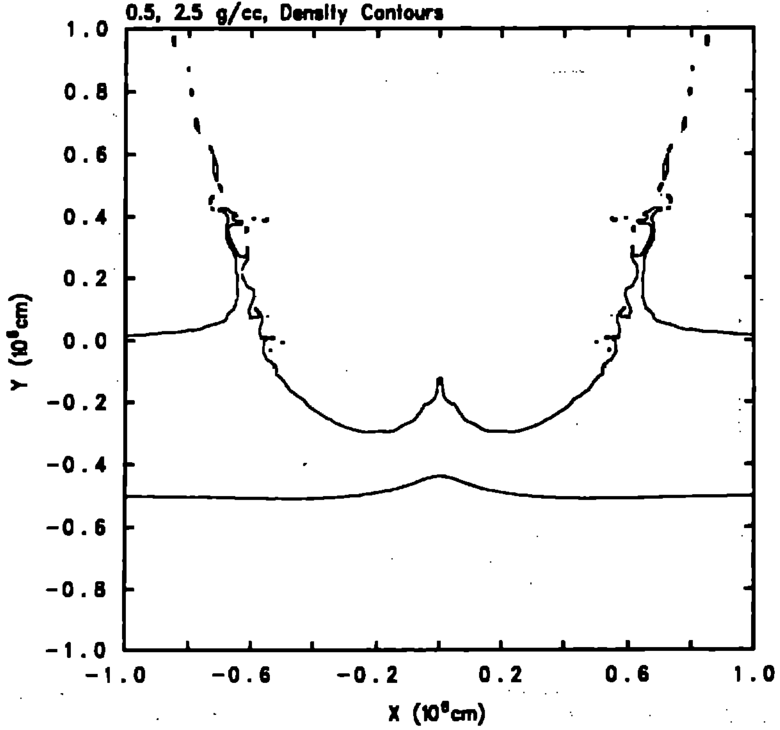


500 m Asteroid Impact into Ocean

CTH 5823 Time=2.10024×10^1



500 m Asteroid Impact into Ocean
CTH 6801 Time=2.50025×10^1



500 m Asteroid Impact into Ocean
CTH 8024 Time=3.00015×10^1

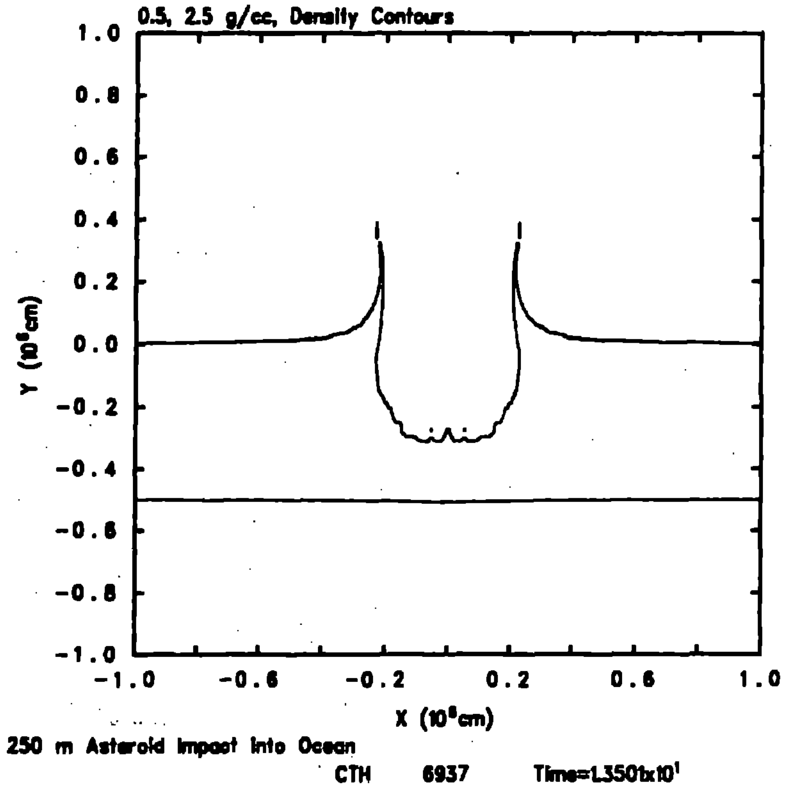


Figure 2. The maximum ocean cavity generated by a 250 meter diameter, 3.32 g/cc asteroid moving 20 kilometers/second impacting 5000 meters of water and a basalt ocean floor. The maximum cavity occurs at 13 seconds.

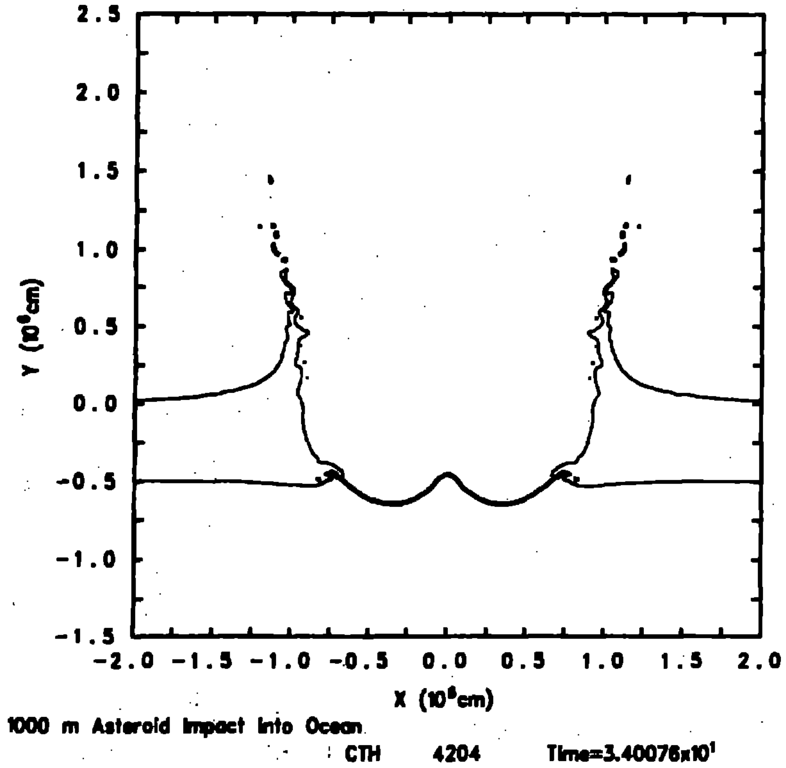


Figure 3. The maximum ocean cavity generated by a 1000 meter diameter, 3.32 g/cc asteroid moving 20 kilometers/second and impacting 5000 meters of water and a basalt ocean floor. The maximum cavity occurs at 34 seconds.

Table 1.
Asteroid Tsunami Wave Heights

Asteroid Dia (m)	250.	500.	1,000.		
Water Cavity[a] Radius (m) (Ro)	2,500.	5,000.	10,000.	20,000.	30,000.
1.0 km	800.	2800.	5000.	7500.	7900.
2.5 km	300.	1300.		4800.	5500.
5.0 km	150.	600.	1600.	3000.	3800.
10.0 km	72.	350.	900.	2000.	2400.
15.0 km	50.	220.	640.	1600.	2100.
20.0 km	34.	160.	460.	1250.	1700.
25.0 km	28.	120.	360.	1100.	1400.
30.0 km	22.	100.	300.	880.	1200.
40.0 km	16.	70.	220.	680.	900.
45.0 km	14.	62.	190.	600.	810.
50.0 km	12.	55.	170.	525.	720.
60.0 km	10.	43.	135.	425.	600.
70.0 km	8.	38.	110.	350.	510.
100. km		22.	70.	230.	360.
150. km		14.	40.	150.	
H(Ro/R)		EXTRAPO	LATED		
500. km			12.	50.	83.
1000. km			6.	26.	36.
H(Ro/R)	300.	600.	900.	1250.	1200.
	Values[b]	at	R/Ro=4		
Velocity (m/s)	166.	166.	190.	210.	
Wave Length	24 km	32 km	56 km	90 km	
Period	2.5 min	3 min	5 min	7 min	

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[a] CTH Asteroid Model - 3.32 g/cc Dunite, 20 km/sec,
In 5 km Deep Ocean, Basalt Ocean Floor

[b] Tsunami period, wavelength, and velocity increases with run.

Table 2.
Shallow Water Asteroid Tsunami Wave Heights

Asteroid Dia (m)	250.	500.	1,000.
Water Cavity[a] Radius (m) (Ro)	2,500.	5,000.	10,000.
1.0 km			
2.5 km	725.		
5.0 km	550.	1100.	
7.5 km	360.		
9.0 km	300.		
10.0 km	(250.)	560.	1800.
15.0 km		360.	1700.
16.0 km			1500.
17.0 km			1300.
20.0 km	(125.)	250.	
25.0 km	(100.)	(220.)	(800.)
50.0 km	(50.)	(110.)	
75.0 km	(33.)	(73.)	
100. km	(10.)	(55.)	(200.)
150. km		(37.)	(133.)
500. km		(11.)	(40.)
1000. km		(6.)	(20.)
H(Ro/R)	1000.	1100.	2000.
Velocity (m/s)	221.	221.	221.
Wave Length	9 km	17 km	40 km
Period	40 sec	100 sec	180 sec

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[a] CTH Asteroid Model - 3.32 g/cc Dunite, 20 km/sec, In 5 km Deep Ocean, Basalt Ocean Floor
Values in Parenthesis are Calculated from H(Ro/R)

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